Renewable and Sustainable Energy Reviews 16 (2012) 3891–3902

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

A review of concentrating solar power plants in the world and their potential use in Serbia

Tomislav M. Pavlović*, Ivana S. Radonjić, Dragana D. Milosavljević, Lana S. Pantić

University of Niš, Faculty of Science and Mathematics, Department of Physics, Višegradska 33, 18 000 Niš, Serbia

ARTICLE INFO

Article history:
Received 3 August 2011
Received in revised form 13 March 2012
Accepted 13 March 2012
Available online 28 April 2012

Keywords:
Solar energy
Concentrating solar power (CSP) plants
Parabolic trough
Solar power tower
Parabolic dish
Fresnel reflector

ABSTRACT

In the paper description and working principles of the parabolic trough power plants, solar tower power plants, parabolic dish power plants and power plants with Fresnel reflectors in the world and their potential use in Serbia are given. In addition, the examples and technical characteristics of some concentrating solar power plants in the world are given. The paper points out that first CSP plant Solar One was installed in 1982 in USA. Nowadays there are 29 active CSP plants while 31 are being constructed worldwide. Power of parabolic trough power plants is between 0.25 and 354 MW, solar tower power plants 1.5 and 20 MW, parabolic dish power plants 1.5 MW and power plants with Fresnel reflectors 1.4 and 5 MW. The biggest active CSP plant SEGS of 354 MW is located in Mojave Desert in USA. Besides results of considerations on solar energy potential in Serbia, current solar energy activities and future solar power projects in Serbia are given. Special attention is drawn to the Serbian government initiatives and support for the use of renewable sources of energy. In the end a suggestion for the installation of concentrating solar power plant in Serbia is given.

Contents

* Corresponding author. Tel.: +381 18225483; fax: +381 18533014.
E-mail address: pavlovic@pmf.ni.ac.rs (T.M. Pavlović).

1364-0321/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.rser.2012.03.042

1. Introduction

Global increase in the number of population and scope of wealth leads to greater energy consumption. As a result, there is a lack of resources, especially energy and drinking water [1]. The global energy consumption is likely to grow faster than the population growth [2]. It is estimated that the consumption of electrical energy will double in the next 15–20 years [1]. Estimates of the world primary energy consumption are that 80% of the energy supply is provided by fossil fuels [3]. The global challenge for the 21st century and way ahead is to find other means of satisfying energy needs [4]. Irrespective of the ecological arguments, increase of the production of electrical energy generated by renewable sources is necessary so that countries diminish their dependence on the import and the necessity to provide for new resources. Renewable sources are in the long run a valuable alternative. Many areas in the world abound in free solar energy while in some other areas wind and other types of renewable sources of energy impose themselves as a logical choice [1].

Having in mind that fossil fuels on Earth are limited and that their usage ensues the emission of CO_2 that exerts negative influence on the environment, more and more renewable sources of energy are being used worldwide with the Sun as a primary source of energy. By using adequate equipment sun irradiation energy can be converted into thermal and electrical energy. Depending on the temperature of the working fluid we can differ between the low-temperature ($T < 100\,^{\circ}$C), middle-temperature ($100\,^{\circ}\mathrm{C} < T < 400\,^{\circ}$C) and high-temperature solar thermal energy conversion ($400\,^{\circ}\mathrm{C} < T < 4000\,^{\circ}$C). For low-temperature solar energy conversion one uses flat collectors with water and air, for middle-temperature conversion one uses vacuum collectors and collectors with concentrators, and for high-temperature conversion one uses solar furnaces and CSP plants [5,6].

Concentrated solar power (CSP) plants denote plants that generate electrical energy by means of concentrated sun irradiation. CSP plants are composed of the solar concentrators, steam turbine and electricity generator. Solar concentrators can be parabolic troughs, heliostats, parabolic dishes and Fresnel reflectors [7]. CSP plants use concentrators to focus sunlight onto a receiver in which a working fluid is heated up to several hundred Celsius degrees [8]. CSP plants use solar heat to produce steam for electricity generation [9]. For the continuous functioning of the CSP plant during the night and in overcast days a thermal energy from the heat tank or gas as an additional source of energy is used [10,11].

The paper goes on to give a description of the parabolic trough system, solar power tower, parabolic dish system, Fresnel reflectors, comparison and examples of different types of CSP plants, solar energy potential in Serbia, current and future solar energy activities in Serbia.

2. Concentrating solar power (CSP)

2.1. Parabolic trough system

Parabolic trough systems are composed of several linear interconnected parabolic troughs, steam turbine and generator of the electrical energy. In the focuses of cylindric-parabolic reflectors a vacuumed glass tube is located. Within the vacuum glass tube there is an absorption tube with the flowing working fluid. In order to achieve maximal increase in the absorption of the sun irradiation and reduce heat losses, absorption tube is spectrally selective colored. High absorption coefficient of sun irradiation of the absorption tube and its position in the focus of the parabolic trough, provides for efficient heating of the working fluid. Due to low emission of the absorption tube, heat losses of the parabolic troughs are reduced to the lowest. Parabolic troughs are positioned toward the south, upright or horizontally. When set upright by means of rotational carrier they follow the sun's position in the east–west direction. When positioned horizontally, they change the tilt so as to track the changes in the sun's height during the day. By means of parabolic troughs it is possible to heat mineral oil up to 400 °C. Thus, heated working fluid is by pumps transferred from the absorption tube into the heat exchanger. Here a heat exchanger converts the heat into steam which is then sent to a turbine to produce electricity. Parabolic trough systems provide the best land-use factor of any solar technology [3,5,10,12–16]. Schematic view of parabolic trough power plant is shown in Fig. 1.

Parabolic trough power plant of 14 MW, SEGS I was installed by Luz International Co. in 1984 in South California and it was combined with gas so as to enable the plant to function continuously, even during reparation and in overcast weather. The linear parabolic trough technology is more advanced than all the other CSP technologies [12].

2.2. Solar power tower

Solar power tower is composed of several heliostats, tower with top situated receiver with the working fluid and the generator of the electrical energy. Heliostats are composed of several flat mirrors that focus concentrated sun irradiation onto the receiver. Each heliostat has its own mechanism for Sun tracking along two axis. Receivers are made of ceramics or the metals stable at high temperatures. Working fluid can be water, molten salt, liquid sodium or air. Under the exertion of steam or molten salt, steam generator of electricity converts mechanical work into electrical energy which is then given to electro-distributive grid. Exhausted steam from the turbine is condensed in a condenser, and the condensate thereafter is pumped into the boiler where it again receives heat from the solar receiver, and the cycle is repeated [3,5,10,12,14,15,18]. Schematic view of solar tower power plant is shown in Fig. 2.

First solar power towers used water as a working fluid. However, nowadays in USA solar power towers use as a working fluid mostly molten nitrate salt that is not flammable, is non-toxic, and is better as a storage of heat than water. In Europe solar power towers use air as a working fluid. Solar power towers are cost efficient and profitable if they are power of 50–100 MW. When compared to other CSP technologies, solar power towers require the biggest area per unit of generated energy and large quantity of water. Efficiency of solar power towers is influenced by optical characteristics of heliostat, cleanliness of the mirror, precision of the tracking system, etc. Solar power towers can operate when combined with conventional fossil-fired plants such as the natural gas combined-cycle and

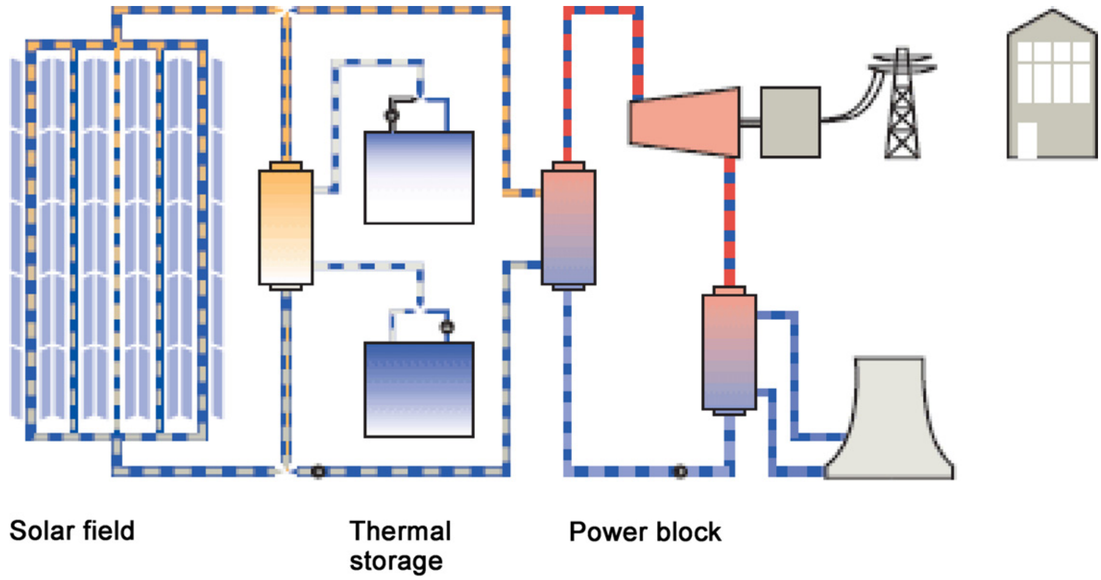

Fig. 1. Schematic view of parabolic trough power plant [17].

coal-fired or oil-fired Rankine plants. In hybrid plants solar energy can be used to reduce the use of fossil fuel or to increase the power input to the steam turbine [13].

2.3. Parabolic dish system

Parabolic dish system is composed of parabolic reflectors in the form of dish, Stirling engine placed in the focus of the dish and generator of the electrical energy. During the day solar dishes are automatically directed toward the Sun and they reflect sun irradiation toward the Stirling engine. By means of parabolic dishes with factor of concentration ratio of around 2000, in their focus a temperature of 700 °C is reached and pressures of working fluids of 200 bar [3,10,11,13,14,15].

Parabolic dishes have diameter of 5–10 m and the surface of 40–120 m^2. Reflecting surface of parabolic dishes is made of aluminum or silver on glass or plastic. The best performance was found in mirrors of silver on glass, thickness of around 1 mm. In order to improve reflection it is desirable that glass contains certain percentage of iron. Mirrors of silver on glass with iron have solar reflectance of 90–94%. Power of the individual parabolic dish system is between 5 and 50 kW [12,20]. Schematic view of parabolic dish with Stirling engine is shown in Fig. 3.

In Stirling engine the heat of concentrated sun irradiation is converted into mechanical work. To Stirling engine a generator of electrical energy is connected. The efficiency of the parabolic dish system with Stirling engine is 30% [12,13,20].

2.4. Fresnel reflectors

Solar thermal power plants with Fresnel reflectors are composed of flat or slightly curved Fresnel reflectors, receivers of the concentrated sun irradiation, cylindrical-parabolic reflector, steam turbine and generator of the electrical energy. During the day Fresnel reflectors are automatically directed toward the Sun and they reflect sun irradiation toward cylindrical-parabolic reflector in whose focus there is a receiver in the shape of long tubes with running water. Under the influence of the reflected sun irradiation water in receiving tubes evaporates and under pressure runs into the steam turbine that starts generator of the electrical energy [3,10,13–15,22,23]. Schematic view of CSP plant with Fresnel reflectors is shown in Fig. 4.

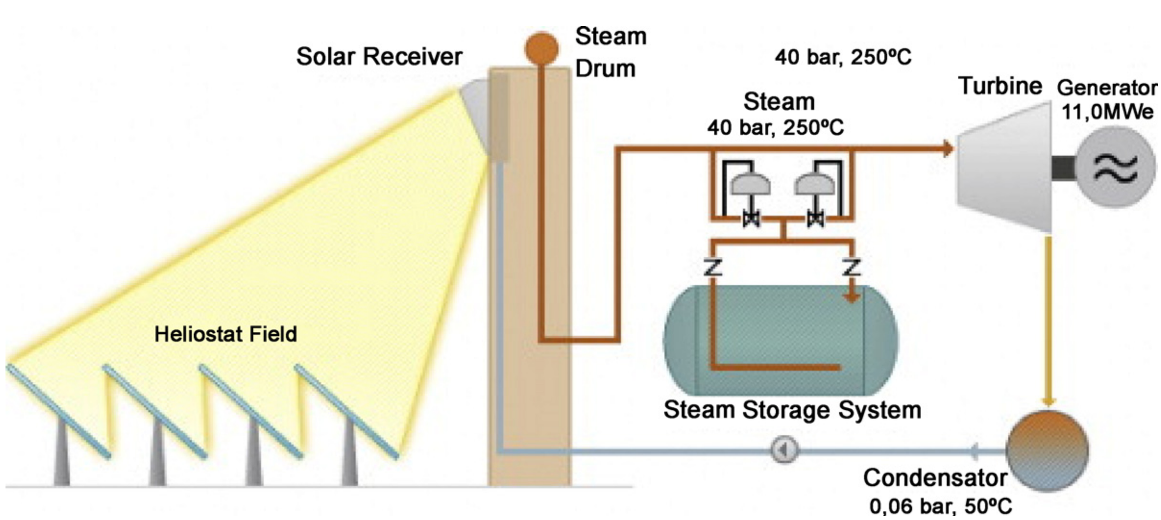

Fig. 2. Schematic view of solar tower power plant [19].

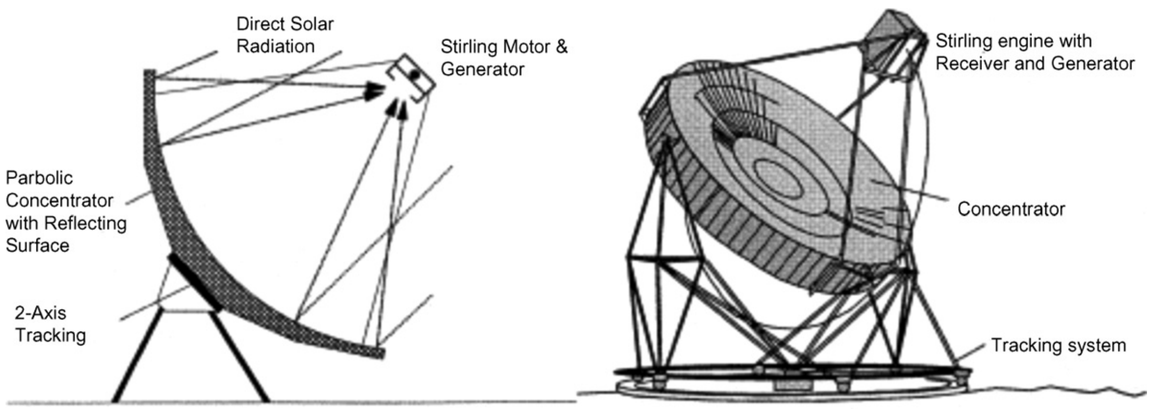

Fig. 3. Schematic view of parabolic dish with Stirling engine [21].

Table 1
Types of installed and CSP plants in construction in the world [26].

CSP plants	Active	In construction
With parabolic troughs	20	27
With solar tower	5	2
With parabolic dishes	1	1
With Fresnel reflectors	3	1
Total	29	31

Fresnel reflectors are composed of a large number of flat mirrors that are cheaper than parabolic mirrors. On the same surface one can place larger number of Fresnel reflectors than parabolic mirrors. Fresnel reflectors can be used in high or small capacity CSP plants with Fresnel reflectors [10].

2.5. Comparison of different types of CSP plants

CSP plants are one of several renewable energy technologies with significant potential to meet a part of future energy demand [25]. CSP technology has the capacity to provide for about 7% of the total electricity needs projected for the world by 2030 and 25% by 2050 (considering a high-energy-saving, high-energy-efficiency scenario) [3]. Up to date a large number of CSP plants were installed out of which 29 are active and 31 are being constructed. In Table 1 data on types of the installed and CSP plants that are still being constructed worldwide are given [26]. The CSP market is expected to keep growing at a significant pace [9].

In Table 2 literature data referring to some characteristics and prices of active CSP plants in the world are given [11,13].

Land area needed to install CSP plant depends on the type of concentrator that CSP plant uses. To install solar tower power plant the biggest area is needed. In case parabolic trough power plant does not have heat storage, a land area of around 25 m^2/kW is needed for its installation. When solar tower power plant does not have heat storage around 45 m^2/kW is needed for its installation [27].

3. Examples: a review

3.1. Parabolic trough power plants

Based on the data found on [26] nowadays there are 20 active parabolic trough power plants worldwide: 11 in Spain, five in USA, two in Iran, one in Italy and one in Morocco. The same site data claim that worldwide 27 parabolic trough power plants are being constructed: 22 in Spain, two in USA and one in India, one in Egypt, one in Algeria (see Tables 3 and 4).

In Spain there are active parabolic trough power plants: Solnova of 150 MW, Andasol Solar Power Station of 100 MW, Extresol Solar Power Station of 100 MW, Ibersol Ciudad Real of 50 MW, Alvarado I of 50 MW, La Florida of 50 MW, Majadas de Tiétar of 50 MW, La Dehesa of 50 MW, Palma del Rio 2 of 50 MW, Palma

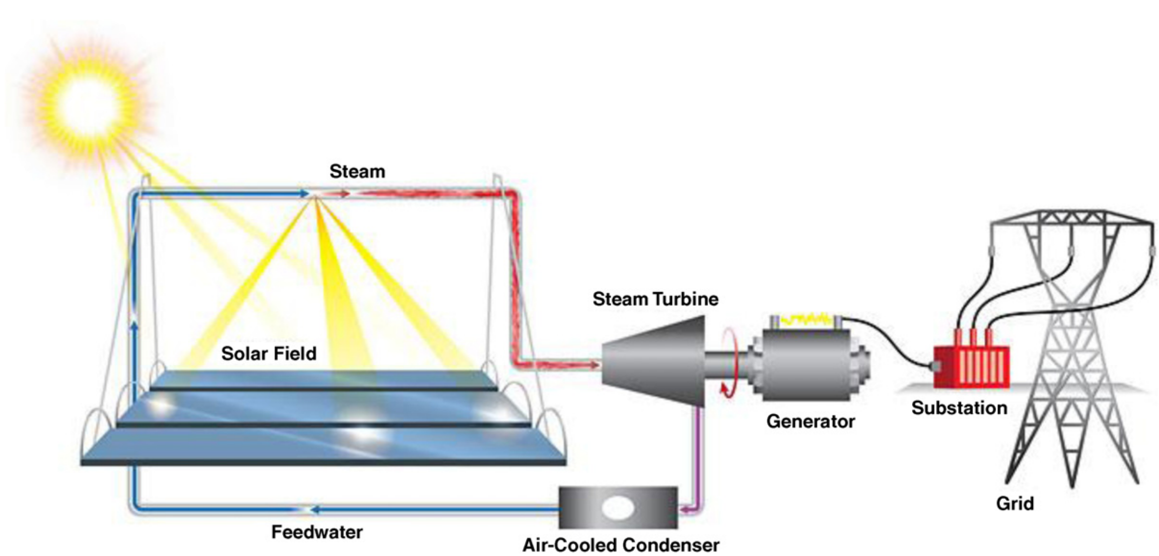

Fig. 4. Schematic view of CSP plant with Fresnel reflectors [24].

Table 2
Some characteristics and prices of active CSP plants in the world [11,13].

Type of CSP plant	Plant size (MW)	Thermal efficiency (%)	Demonstrated annual solar efficiency (%)	Land use (m^2/MW ha)	Basic plant cost ($/W)	Specific power (W/m^2)	Capital cost ($/W)
Parabolic trough	10–200	30–40	10–15	6–8	3.22	300	2.9–3.22
Power tower	10–150	30–40	8–10	8–12	3.62	300	2.4–3.62
Dish-Stirling	2.5–100	30–40	16–18	8–12	2.65	200	2.65–2.9

del Rio 1 of 50 MW and Manchasol-1 of 50 MW. In USA following parabolic trough power plants are active: Solar Energy Generating Systems of 354 MW, Martin Next Generation Solar Energy Center of 75 MW, Nevada Solar One of 64 MW, Keahole Solar Power of 2 MW and Saguaro Solar Power Station of 1 MW. In Iran currently two parabolic trough power plants are installed: Yazd integrated solar combined cycle power station of 17 MW and Shiraz solar power plant of 0.25 MW. In Morocco one plant is active Beni Mathar Plant of 20 MW, and in Italy Archimede solar power plant of 5 MW [26].

3.1.1. Solar Energy Generating System – SEGS (USA)

CSP plant SEGS (Solar Energy Generating Systems) of 354 MW is located in USA, in the Mojave Desert, in San Bernardino county on three locations: Daggett, Kramer Junction and Harper Lake. It is composed of nine CSP plants and is the largest solar energy generating facility in the world [10,28].

CSP plant SEGS has 936,384 mirrors that are placed on the surface of 6.5 km^2. If the mirrors were lined up they would take up the length of 370 km. Parabolic mirrors with reflection of 94% are made of glass in the shape of half tubes. During the day mirrors are automatically directed toward the Sun. Sun irradiation is reflected from the mirrors and is directed to the central tube containing synthetic oil which is heated to 400 °C. Reflected irradiation focused to the central tube is from 71 to 80 times more intensive than the incident sun irradiation. Synthetic oil transmits its heat onto the water that evaporates and starts the steam turbine with Rankine cycle. In CSP plant SEGS each year on average 3000 mirrors are changed. Most frequent cause of mirror breaking is wind. CSP plant uses automatic mechanism for periodic mirror cleaning. CSP plant SEGS provides electrical energy for 232,500 households. To generate electrical energy it uses sun irradiation and natural gas. By means of sun irradiation 90% of electrical energy is generated. Natural gas is used only when solar energy is insufficient to meet the demand for electrical energy [10,26].

CSP plant SEGS uses three generations of parabolic trough concentrators: LS-1, LS-2 and LS-3 of the Israely-American company Luz International Ltd. Luz system concentrators denote standards to compare for all the other concentrators. These concentrators have proven reliability and are suitable for the use in commercial CSP plants [6,29]. Company Luz manufactured in 1984 parabolic trough concentrator LS-1, in 1985 parabolic trough concentrator LS-2, and in 1989 parabolic trough concentrator LS-3. In order to increase electricity generation in CSP plants and reach higher fluid outlet temperatures, bigger concentrators with higher concentration ratio were aimed at. To decrease the manufacturing costs company Luz made a concentrator LS-3, bigger than the previous ones. Use of LS-3 concentrator did not lower the manufacturing costs as expected. LS-3 concentrator reaches the same maximal temperature (390 °C) as LS-2, but LS-3 is not easy to install and maintain as LS-2 is [29,30]. Receiving tube of Luz concentrator is of spectrally colored stainless steel. Receiving tube is situated in vacuum glass tube with low content of iron (0.015%). In order to increase the transmission of sun irradiation glass tube has antireflection coating. Luz concentrators are made of silver glass thickness of 4 mm, they are protected with five layers, one copper and four varnish, and they have a low content of iron. Glass gets its parabolic shape by heating in precise parabolic molds and special furnaces. Selective layer used in LS-1 and LS-2 concentrators is black chrome, while in LS-3 concentrator a new ceramic-metal layer thickness of 0.3 μm is used [6].

Integral component of the CSP plant SEGS I is a heat tank enabling the plant to function continuously 3 h after the sun set. CSP plant SEGS I uses as a heat transfer fluid and heat storage material mineral oil, Caloria, specially manufactured for this purpose. Main advantage of this technology for heat storage is the fact that the same fluid is used as a heat transfer fluid and as a material for heat storage. Main drawback is that substantial quantity of oil is needed for the storage in heat tanks which increases the manufacturing and maintenance costs of this thermal power plant. Caloria oil took

Table 3
Indicative land area requirements for different types of active CSP plants [27].

CSP plant	Type of CSP plant	Capacity (MW)	Thermal storage (h)	Land area (m^2)	Specific land area (m^2/kW)
SEGS	Parabolic trough technology	354	–	6,400,000	18
Andasol	Parabolic trough technology	50	7.5	2,000,000	40
Solnova	Parabolic trough technology	50	–	1,200,000	24
PS10	Solar tower technology	11	1	600,000	55
PS20	Solar tower technology	20	–	900,000	45

Table 4
CSP plant SEGS of 354 MW in Mojave Desert, USA [10].

Plant	Year built	Location	Net turbine capacity (MW)	Field area (m^2)	Oil temperature (°C)
SEGS I	1984	Daggett	14	82,960	307
SEGS II	1985	Daggett	30	165,376	316
SEGS III	1986	Kramer Jct.	30	230,300	349
SEGS IV	1986	Kramer Jct.	30	230,300	349
SEGS V	1987	Kramer Jct.	30	233,120	349
SEGS VI	1988	Kramer Jct.	30	188,000	391
SEGS VII	1988	Kramer Jct.	30	194,280	391
SEGS VIII	1989	Harper Lake	80	464,340	391
SEGS IX	1990	Harper Lake	80	483,960	

Table 5
Technical characteristics of CSP plant Solnova [28].

Name	Solnova 1, Solnova 3 and Solnova 4 for each
Location	Sanlúcar la Mayor, Spain
Lat/long location	37°26′30,97″ North 6°14′59,98″ West
Capacity	50 MW
Land area	115 ha
Solar-field aperture area	300,000 m^2
# of Solar Collector Assemblies (SCAs)	360
# of SCAs per loop	4
SCA aperture area	833 m^2
SCA length	150 m
# of Heat Collector Elements (HCEs)	12,960
Heat-transfer fluid type	Thermal oil
Solar-field outlet temperature	393 °C
Power cycle pressure	100 bar

42% of total costs invested in CSP plant SEGS I. This is exactly the reason why other SEGS CSP plants do not use this oil [6,19].

3.1.2. Solnova Solar Power Station (Spain)

CSP plant Solnova Solar Power Station of 150 MW is situated in Sanlúcar la Mayor, in Spain. It is composed of five separate units out of which three are active: Solnova 1 of 50 MW, Solnova 3 of 50 MW and Solnova 4 of 50 MW. This CSP plant can also use natural gas as a secondary fuel for the generation of electrical energy [26]. CSP plant Solnova 1 uses parabolic troughs type ET-150, lined up in 90 rows and oriented toward north–south. Concentrators ET-150 are around 150 m long and their aperture size is around 820 m^2. Total reflecting surface of these concentrators is 260,000 m^2, and land surface occupied by Solnova 1 is around 1,200,000 m^2 [6,27]. Technical characteristics of CSP plant Solnova are given in Table 5.

This power plant does not have heat tank and uses as heat transfer fluid synthetic oil that can be heated up to 400 °C. Global annual efficiency of this CSP plant is 19% [6].

3.1.3. Andasol (Spain)

CSP plant Andasol of 100 MW is the first commercial parabolic trough power plant in Europe and the first in the world with heat storage. CSP plant Andasol is composed of two CSP plants Andasol 1 and Andasol 2, each power of 50 MW. These thermal power plants are located near town Guadix, in Granada, in Spain [26,28].

Because of the high altitude (1100 m) and the semi-arid climate the site has exceptionally high annual direct insolation. Each collector has a surface of 51 ha; it occupies about 200 ha of land. CSP plant Andasol uses parabolic trough concentrators type SKAL-ET. SKAL-ET concentrators SKAL-ET represent the third generation of Euro Trough concentrators. Solar field of each Andasol thermal power plant contains 624 concentrators with total reflecting surface of over 510,120 m^2 and is located on the surface of 2,000,000 m^2 [6,26,27,31]. Technical characteristics of CSP plant Andasol are given in Table 6.

CSP plant Andasol uses as heat transfer fluid superheated steam and as a heat storage media molten salts of sodium and potassium nitrate. Heat storage is composed of cold tank temperature of 291 °C and hot tank temperature of 384 °C. In the heat tank of the CSP plant Andasol there is molten salts of 40% sodium nitrate ($NaNO_3$) and 60% potassium nitrate (KNO_3). Heat storage has heat capacity of 1010 MW h of heat energy. Heat from the heat tank is used for the generation of electrical energy after the sunset, in the overcast weather, etc. Heat tank enables CSP plant to function around 7.5 h after the sunset and to almost double the working hours of the plant during the year. Average annual efficiency of Andasol CSP plant is 14.7%. During the year up to 15% of electrical energy is generated by Andasol 1 CSP plant using gas [19,31].

Table 6
Technical characteristics of CSP plant Andasol [28].

Name	Andasol 1, Andasol 2
Location	Guadix, Granada, Spain
Lat/long location	37°13′50,83″ North 3°4′14,08″ West
Capacity	50 MW
Land area	200 ha
Solar-field aperture area	510,120 m^2
# of Solar Collector Assemblies (SCAs)	624
# of SCAs per loop	4
SCA aperture area	817 m^2
SCA length	144 m
# of modules per SCA	12
# of Heat Collector Elements (HCEs)	11,232
Heat-transfer fluid type	Diphenyl/biphenyl oxide
Solar-field inlet temperature	293 °C
Solar-field outlet temperature	393 °C
Power cycle pressure	100 bar
Storage type	2-tank indirect
Storage capacity	7.5 h
Thermal storage description	28,500 tons of molten salt. 60% sodium nitrate, 40% potassium nitrate. Heat capacity 1010 MW h. Tanks are 14 m high and 36 m in diameter.

3.2. Solar tower power plants

Based on the data found on [26] nowadays there are 5 active solar tower power plants worldwide: three in Spain, one in USA, one in Germany. The same site data claim that worldwide 2 solar tower power plants are being constructed: one in USA and one in France. Spain has active CSP plants Planta Solar 20 of 20 MW, Gemasolar of 17 MW and Planta Solar 10 of 11 MW, in USA active solar tower power plants are Sierra Sun Tower of 5 MW and in Germany Jülich Solar Tower of 1.5 MW [26].

3.2.1. Solar One and Solar Two (USA)

Near the town Barstow in California in 1982 Southern California Edison Co. constructed and installed first CSP tower plant, Solar One. CSP plant Solar One of 10 MW was in function from 1982 to 1986. Solar One contained 1818 heliostats with total surface of 72,650 m^2 which focused sun irradiation onto the receiver located on the top of the tower height of 91.43 m. Focused sun irradiation heated water in the receiver up to 620 °C under pressure of 1,339,286 Pa. During cloudy days and over night this CSP plant used heat from the heat tank made of 6800 tons of granular stone and sand located below the plant in cylindric steel tank. As a heat transfer fluid 908,402 l of special hot stable oil was used. CSP plant was completely run automatically and was monitored by computer system [5,32].

Solar One was in 1995 transformed into CSP plant Solar Two by adding new heliostats and it functioned until 1999. Solar Two used the tower of Solar One while heliostat field had a surface of 82,750 m^2. Solar Two used as heat storage medium molten salt of 60% sodium nitrate and 40% potassium nitrate. Thanks to this fact Solar Two could function even 3 h after the sunset. CSP plant Solar Two was pulled down and removed from its site on 25 November in 2009 [32].

3.2.2. Planta Solar 10 (Spain)

CSP plant Planta Solar 10 of 11 MW installed in 2007, is located near Seville, in Andaluzia (Spain). Technical characteristics of CSP plant PS10 are given in Table 7.

Heliostat field of this plant is composed of 624 heliostats called Sanlúcar 120, of the company Abengoa Solar, each surface of 120 m^2. The tower is 115 meters high and has 40 floors. On the top of the tower there is a steam turbine that starts generator for the production of electrical energy. CSP plant PS10 can store saturated steam in a ceramic alumina bed. When CSP plant PS10 is

Table 7
Technical characteristics of CSP plant PS10 [28].

Name	Planta Solar 10 (PS10)
Location	Sanlúcar la Mayor, Spain
Lat/long location	37°26′30,97″ North, 6°14′59,98″ West
Capacity	11 MW
Land area	55 ha
# of heliostats	624
Heliostat aperture area	120 m^2
Heliostat manufacturer (model)	Abengoa (Solucar 120)
Tower height	115 m
Receiver type	Cavity
Heat-transfer fluid type	Water
Receiver outlet temp	250–300 °C
Power cycle pressure	45 bar
Storage capacity	1 h

fully overload part of the steam produced on 250 °C and 40 bar is used to fill the heat tank [19,26,28]. CSP plant PS10 has the average efficiency of the conversion of solar energy into electric during the year around 17.5%, and the efficiency of heat storage is around 92.4%. When there is no sun CSP plant runs on gas [19].

3.2.3. *Planta Solar 20 (Spain)*

CSP plant Planta Solar 20 of 20 MW is located near Seville, in Andaluzia. Technical characteristics of CSP plant PS20 are given in Table 8.

Heliostat field of this plant is composed of 1255 heliostats, each surface of 120 m^2. The tower is 165 m high. On the top of the tower there is a steam turbine that starts generator for the production of electrical energy. Construction of the CSP plant PS20 was begun in 2006 and it was installed in 2009. When compared to PS10, PS20 plant has bigger efficiency, better monitoring system and better thermal energy storage [26]. Solar tower power plants PS10 and PS20 near Seville, in Andaluzia (Spain) are shown in Fig. 5.

3.2.4. *Sierra Sun Tower (USA)*

CSP plant Sierra Sun Tower of 5 MW was installed in 2009 in Lancaster, CA (USA). As of spring 2010 Sierra Sun Tower is the only commercial CSP tower facility in North America [26]. Technical characteristics of CSP plant Sierra Sun Tower are given in Table 9.

CSP plant Sierra Sun Tower takes up land area of 8 ha, has two towers and 24,360 flat mirrors which focus sun irradiation to the towers. Construction of Sierra Sun Tower took 12 months and engaged 300 workers. The plant has 21 full time employees. Sierra Sun Tower provides electrical energy for 4000 households [26].

3.2.5. *Jülich Solar Tower (Germany)*

CSP plant Jülich Solar Tower of 1.5 MW, started running in 2009, is located in Jülich in the west part of Germany. Technical characteristics of CSP plant Jülich Solar Tower are given in Table 10.

Table 8
Technical characteristics of CSP plant PS20 [28].

Name	Planta Solar 20 (PS20)
Location	Sanlúcar la Mayor, Spain
Lat/long location	37°26′30,97″ North, 6°14′59,98″ West
Capacity	20 MW
Land area	80 ha
# of heliostats	1255
Heliostat aperture area	120 m^2
Heliostat manufacturer (model)	Abengoa (Solucar 120)
Tower height	165 m
Receiver type	Cavity
Heat-transfer fluid type	Water
Receiver outlet temp	250–300 °C
Power cycle pressure	45 bar
Storage capacity	1 h

Fig. 5. Solar tower power plants PS10 and PS20 near Seville, in Andaluzia (Spain) [26].

On 17 ha there are 2150 movable mirrors each surface of 8 m^2. Receiver is located on the tower, 60 m high. Concentrated sun irradiation heats the air in receiver up to 680 °C. Hot air is used to heat the water up to 485 °C and to generate steam under pressure of 27 bar. This plant provides 350 households with electrical energy [33].

3.3. *Parabolic dish power plants*

Based on the data found on [26] nowadays there is only one active parabolic dish power plant called Maricopa Solar of 1.5 MW, in USA. The same site data claim that worldwide only one parabolic dish power plant is being constructed in Spain.

3.3.1. *Maricopa Solar (USA)*

The first commercial parabolic dish power plant is in USA, Maricopa Solar of 1.5 MW, near the town of Peoria in Arizona. Maricopa Solar is composed of 60 solar dishes, each having Stirling engine, and generator of electrical energy power of 25 kW. This CSP plant uses silverplated glass mirrors with solar reflectance 94% and Stirling engine with four cylinders and hydrogen as a working fluid

Table 9
Technical characteristics of CSP plant Sierra Sun Tower [28].

Name	Sierra Sun Tower
Location	Lancaster, CA
Lat/long location	34°46′ North, 118°8′ West
Capacity	5 MW
# of heliostats	24,360
Heliostat aperture area	1136 m^2
Heliostat manufacturer	eSolar
Tower height	55 m
Receiver type	Dual-cavity receiver and tubular external receiver
Heat-transfer fluid type	Water
Receiver inlet temp	218 °C
Receiver outlet temp	440 °C

Table 10
Technical characteristics of CSP plant Jülich Solar Tower [33,34].

Name	Jülich Solar Tower
Location	Jülich, Germany
Lat/long location	50°55′0″ North, 6°23′58″ East
Capacity	1.5 MW
Land area	17 ha
# of heliostats	2150
Heliostat aperture area	8 m^2
Tower height	60 m

Table 11
Technical characteristics of CSP plant Maricopa Solar [28].

Name	Maricopa Solar
Location	Peoria, AZ
Lat/long location	33°33′31,0″ North, 112°13′7,0″ West
Capacity	1.5 MW
Land area	15 acres
# of dishes	60
Dish description	Each SunCatcher produces 25 kW of power
Dish manufacturer (model)	Stirling Energy Systems (SES) (SunCatcher™)

[35]. Technical characteristics of CSP plant Maricopa Solar are given in Table 11.

Concentrated sun irradiation heats hydrogen to 750 °C. Air is used to cool Stirling engine. CSP plant Maricopa Solar is used to demonstrate possibilities of the generation of the electrical energy and for the commercial production of electrical energy [36,37].

3.4. Power plants with Fresnel reflectors

Based on the data found on [26] nowadays there are 3 active power plants with Fresnel reflectors in USA, Spain and Australia. In USA active CSP plant is Kimberlina of 5 MW, in Spain it is Puerto Errado 1 of 1.4 MW and in Australia it is Liddell Power Station of 2 MW. The same site data claim that worldwide one power plant with Fresnel reflectors is being constructed in Spain.

3.4.1. Kimberlina (USA)

The first Compact Linear Fresnel Reflectors (CLFR) project in North America, Kimberlina of 5 MW, is located in Bakersfield in California. Technical characteristics of CSP plant Kimberlina are given in Table 12.

In this CSP plant thirteen narrow, flat Fresnel reflectors make up one group. Each single reflector tracks and focuses sun irradiation toward the tubes located above the reflectors. Tubes contain water that evaporates under the influence of the concentrated sun irradiation. Overheated steam, at the temperature of 400 °C, activates turbine and the generator of electrical energy as well [26].

3.4.2. Puerto Errado 1 (Spain)

Power plant with Fresnel reflectors Puerto Errado 1 of 1.4 MW is located in Calasparra in Spain. Technical characteristics of CSP plant Puerto Errado 1 are given in Table 13.

This CSP plant was put into function in April, 2009. On 7 ha there are two rows of Fresnel reflectors, each 806 m in length. Steam is produced by concentrating a direct sun irradiation toward the linear receiver which is 7.40 m above the ground [22,26,28].

3.4.3. Liddell Power Station (Australia)

In Lake Liddell, in New South Wales, in Australia, coal fired thermal power plant Liddell Power Station was upgraded with CSP plant with Fresnel reflectors. Thus a consumption of coal for the production of electrical energy and the emission of 4000 tons of carbon dioxide annually was reduced [26,38]. Technical characteristics of CSP plant Liddell Power Station are given in Table 14.

Table 12
Technical characteristics of CSP plant Kimberlina [28].

Name	Kimberlina Solar Thermal Power Plant
Location	Bakersfield, CA
Lat/long location	35°34′0,0″ North, 119°11′39,1″ West
Capacity	5 MW
Land area	12 acres
# of lines	3
Line length	385 m
Mirror width in line	2 m
# of mirrors across line	10
Collector manufacturer	Ausra
Receiver type	Non-evacuated
Receiver length	385 m
Heat-transfer fluid type	Water
Power cycle pressure	40 bar

Table 13
Technical characteristics of CSP plant Puerto Errado 1 [28].

Name	Puerto Errado 1 Thermosolar Power Plant (PE1)
Location	Calasparra, Spain
Lat/long location	38°16′42,28″ North, 1°36′1,01″ West
Capacity	1.4 MW
Land area	7 ha
# of lines	2
Line length	806 m
Mirror width in line	16 m
Collector manufacturer (model)	Novatec Solar España S.L. (Nova-1)
Heat-transfer fluid type	Water
Solar-field inlet temp	140 °C
Solar-field outlet temp	270 °C
Power cycle pressure	55 bar

This CSP plant has 500 Fresnel reflectors dimensions of 12 m × 2 m on the area of 18,000 m^2. Sun irradiation that is reflected from the Fresnel reflectors heats and evaporates water in tubes located in the focus of the Fresnel reflectors. Steam activates the turbine and the turbine activates the generator of electrical energy [38].

4. Solar energy potential in Serbia

Serbia is located between 41°46′40″ and 46°11′25″ of the north latitude and 18°06′ and 23°01′ east longitude. Serbia belongs to the continental climate regions that can be divided into the continental climate in the Panonic lowlands, moderate-continental climate in lower parts of the mountain region and the mountain climate on high mountains. The biggest influence on the climate in Serbia is exerted by the air masses formed over Siberia, Arctic, Atlantic Ocean, African land and the Mediterranean. Over these areas a field of high air pressure is formed. On the territory of Serbia often cold air from the Siberia penetrates but rarely from the Artics.

North part of Serbia comprises a vast Panonic area which is wide open and exposed to the climate influences coming from the north and the east. The Panonic lowlands show continental climate that encompasses Vojvodina and its edge until 800 m of height. Continental climate is characterized by extremely hot summers with insufficient humidity. Winters are long and harsh and autumns and springs are mild and short. Mean annual air temperatures in the Panonic area are increasing from the west toward the east and from the north to the south.

A moderate-continental climate is dominant in the mountain range of Serbia of 800–1400 m altitude. It is characterized by moderate hot summers, autumns longer and hotter than springs and cold winters. A mountain climate reins in the range over 1400 m of latitude. On the territory of Serbia it is most present on the mountains Šar-planina, Prokletije, Kopaonik, Stara planina, etc. This climate type is characterized by long, cold and snowy winters and short and chilly summers. Cloudiness in the Mountain region is from 55% to 60% annually. Sun shining in the Mountain region of

Table 14
Technical characteristics of CSP plant Liddell Power Station [26,39].

Name	Liddell Power Station
Location	Lake Liddell, Australia
Lat/long location	32°22′26″S, 150°58′40″E
# of lines	4
Line length	403.2 m
Collector manufacturer (model)	Novatec Solar España S.L. (Nova-1)
Operating temperature	270 °C
Operating pressure	55 bar

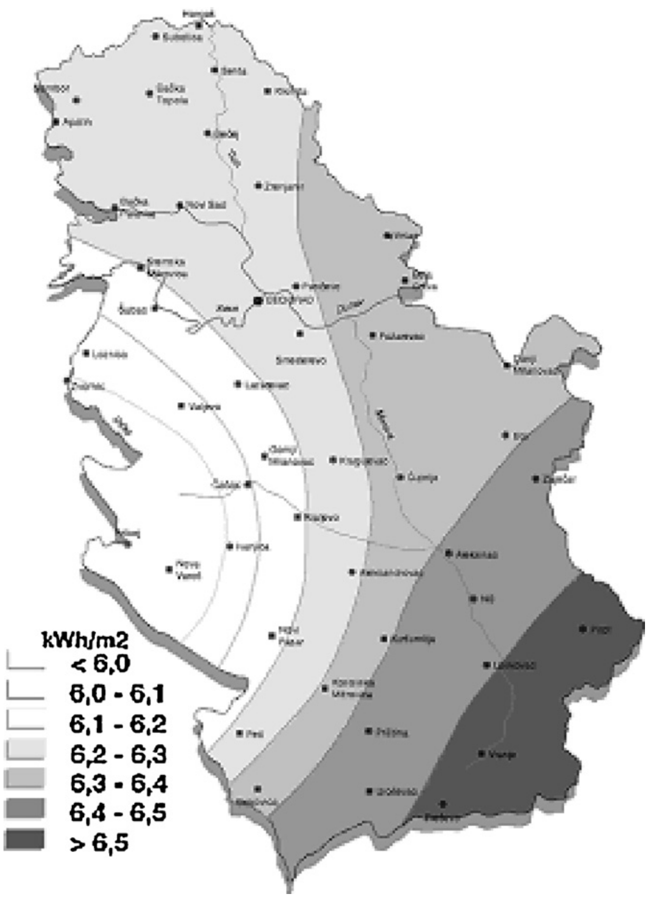

Fig. 6. Average daily global solar irradiation on horizontal plane in July in Serbia [41].

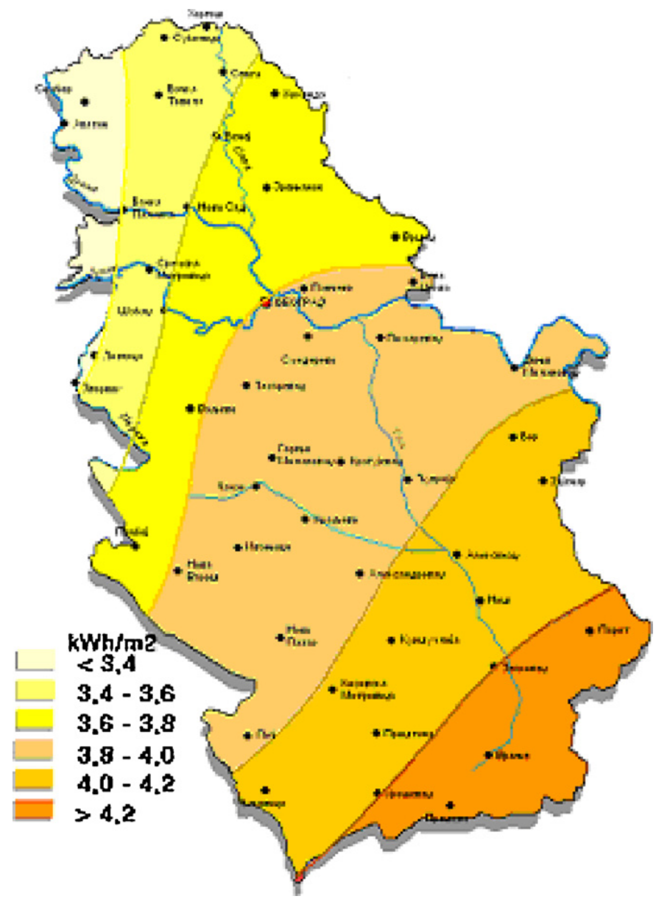

Fig. 7. Annual average of daily energy of global solar irradiation on horizontal plane in Serbia [41].

Serbia is 1500–2000 h annually. Such a small span of sunshine is a consequence of high cloudiness, especially in winter time. Sunshine span is the smallest on the mountains. On Tara sun shines 1700 h annually, or 4.9 h a day. On Kopaonik annual sunshine is 1741 h, or 5 h a day. Precipitation in the Mountain region is high. On average Mountain region has 1700 mm of precipitation annually [40].

Results of long term meteorological measurements have shown that natural potentials of climatic resources of Serbia are very good. In Serbia the energy potential of the sun irradiation and potential of biomass is around 30% higher than in the Middle Europe (average annual sun irradiation energy in Europe is 1096 kW h/m^2 year, and in Serbia it is around 1400 kW h/m^2 year). Mean values for January are in the range from 1.1 kW h/m^2 in the north of the country, to 1.7 kW h/m^2 in the south. Map for July indicates the least energy in the west part of the country and maximal energy in the south-east (Fig. 6). Such spatial distribution is caused by the influence of daily cloudiness, which is most pronounced in the mountainous regions. Mean values for July are in the range from 5.9 to 6.6 kW h/m^2 [41,42]. Average daily global solar irradiation on horizontal plane in July, in Serbia is shown in Fig. 6. Annual average of daily energy of global solar irradiation on horizontal plane in Serbia is shown in Fig. 7 [42].

The yearly mean map appears like a compromise between the two first. Mean values for the year are in the range from 3.3 to 4.3 kW h/m^2.

Comparison of solar irradiation on horizontal, vertical and optimally inclined plane, optimal inclination and ratio of diffuse to global solar irradiation for some cities where CSP plants are installed in the world and some cities in Serbia obtained by programs in Refs. [34,43], are given in Table 15.

Based on data in Table 15 it can be seen that in all given cities in Serbia the intensity of sun irradiation is higher than the intensity of sun irradiation in Jülich (Germany). Besides, in Serbia, ratio of diffuse to global sun irradiation is by 17% smaller than the ratio of diffuse to global sun irradiation in Jülich.

5. Current solar energy activities in Serbia

Renewable energy policy in the Republic of Serbia and the analysis of the renewable energy production sector in Serbia are given in the paper [44,45]. Opportunities and challenges for a sustainable energy policy in SE Europe: SE European Energy Community Treaty and perspectives of sustainable development in countries of Southeastern Europe are given in the paper [46,47]. Kyoto Protocol implementation in Serbia as precognition of sustainable energetic and economic development is given in the paper [48]. Energy efficiency in Serbia-research and development activity is presented in the paper [49]. National energy efficiency program in Serbia – strategy and priorities for the future is given in the paper [50]. Comparison and assessment of electricity generation capacity for different types of PV solar plants of 1 MW in Soko Banja, Serbia are given in the paper [51]. Perspectives and assessments of solar PV power engineering in the Republic of Serbia are given in the paper [52].

Research in the area of renewable sources of energy has solid foundations in the National program of energy efficiency of the Ministry of Science in Serbia. However, application of attained technological knowledge is legging off, especially the realization of demo-projects due to the lack of incentive measures.

Table 15
Comparison of solar irradiation on horizontal, vertical and optimally inclined plane, optimal inclination and ratio of diffuse to global solar irradiation for some cities where CSP plants are installed in the world and some cities in Serbia obtained by programs in Refs. [34,43].

Location	Solar irradiation on horizontal plane (W h/m^2/year)	Solar irradiation on vertical plane (W h/m^2/year)	Solar irradiation on optimally inclined plane (W h/m^2/year)	Optimal inclination (°)	Ratio of diffuse to global solar irradiation	Reference
Bakersfield, USA	5311	3623	5879	55		[43]
Peoria, USA	5281	3696	5900	56		[43]
Sanlúcar la Mayor, Spain	4740	3390	5380	33	0.37	[34]
Guadix, Spain	4750	3400	5390	33	0.38	[34]
Calasparra, Spain	4650	3450	5350	34	0.37	[34]
Jülich, Germany	2630	2050	2960	34	0.59	[34]
Newcastle, Australia	4590	3154	5031	57		[43]
Subotica, Serbia	3430	2620	3910	34	0.49	[34]
Beograd, Serbia	3620	2750	4130	35	0.47	[34]
Kragujevac, Serbia	3710	2790	4210	34	0.47	[34]
Niš, Serbia	3700	2690	4140	33	0.48	[34]
Novi Pazar, Serbia	3890	2990	4470	35	0.46	[34]

Serbia manufactures flat solar collectors with water and the equipment for thermal conversion of sun irradiation. In Serbia, for water heating one uses flat, and rarely, vacuum collectors with forced water circulation. Apart from locally manufactured collectors at the market of Serbia one can also find flat collectors of foreign manufacturers. Serbia does not manufacture solar cells. In Serbia nowadays there are four PV solar power plants of 3–5 kW_p installed on the roofs of schools. Very rare are the cases of the application of solar cells in private households.

Number of installed facilities for the exploitation of renewable sources of energy in Serbia and their current annual energy production is insignificant. Capital invested in up-to-date installed facilities is of small value and is mainly domestic one. From the point of view of the national level financial results, achieved by running these facilities, are humble.

Serbia nowadays almost does not have manufacturers and maintenance service for the equipment used in the exploitation of renewable sources of energy. However, in the area of the exploitation of water energy, biomass and sun irradiation energy for heating purposes there are viable possibilities to include domestic equipment manufacturers.

Most significant barriers for the increased use of renewable sources of energy in Serbia are:

- Lack of clearly defined obligations of the operator of the transmitting, i.e. distribution system to give priority to connecting manufacturers using renewable sources of energy to the grid and giving priority to renewable sources of energy in distribution.
- Lack of large number of equipment standards and procedures for the exploitation of renewable sources of energy.
- Insufficient number of legislative acts on designing, manufacturing, monitoring and installation of the devices that use renewable sources of energy.
- Insufficient number of accredited test laboratories for the facilities using renewable sources of energy.
- Non-economic prices of electrical energy and disparity of the prices of energy related products.

Significant administrative barrier in the course of renewable sources of energy fueled power plant construction is the Law on public companies and public interest activities. This law equates the procedure for giving permission for installation of power plants, fueled by renewable sources of energy, to the permission given to the plants whose power is bigger than 10 MW, which in turn exerts negative influence on the motivation of the potential investors [53,54].

6. Future solar power projects in Serbia

The main aims of Serbia in the area of renewable sources of energy are: more efficient use of one's own potential in energy production; reduction of greenhouse gas emission; decrease in fossil fuels import; development of the local industry and new job openings.

The aim of Serbia up to the end of 2012 is to increase the participation rate of electrical energy generated by the renewable sources of energy by 2.2%, compared to the total national consumption of electrical energy in 2007. Realization of the set goal will be achieved by the increase in the production of electrical energy generated by renewable sources of energy in the scope of 739.1 million kW h in 2012, which is enough to provide for the annual needs for energy of 179,000 households, having average monthly consumption of 350 kW h of electrical energy. Detailed survey and dynamics of the realization of target participation of renewable sources of energy generated electrical energy in Serbia is given in Table 16.

In 2011 the installation of the first PV power plant of 10 MW was begun in Čajetina, on the mountain Zlatibor, in Serbia. Beside this plant several other PV plants are planned to be installed in Serbia.

Up to now Serbia did not install a single CSP plant. Legislative of Serbia does not even mention CSP plant as a source of electrical energy.

Due to a favorable climatic and geographic conditions in Serbia it is possible to install CSP power plants. Having in mind that for the installation of solar tower power plants the largest area is needed, such plants are best to install in Vojvodina. Other parts of Serbia are suitable for the installation of parabolic trough power plants, parabolic dish power plants and power plants with Fresnel reflectors. Parabolic dishes can operate independently of power grids in remote sunny locations so they are appropriate for providing power to people living in isolated villages.

7. Serbian government initiatives and support

Energy policy defined by the Law on energy among other things envisages taking steps to create conditions for stimulation of the use of renewable sources of energy. Congruent with this initiative the Law on energy introduces categories of subsidized energy producers who in their production process use renewable sources of energy, and who are entitled to subsidies, tax, customs and other exemptions in the line with Law and other regulations on taxes, customs and other subsidies and incentives.

Since production of electrical energy from renewable sources of energy is more expensive than the fossil fuels energy production some incentive systems are introduced, that is financial

Table 16
Detailed survey and dynamics of the realization of target participation of renewable sources of energy generated electrical energy in Serbia [54].

		2007	2008	2009	2010	2011	2012
Hydro power plants	MWe	2835.00	2835.00	2835.00	2835.00	2835.00	2835.00
over 10 MW	GWh	9974.00	10,032.00	10,368.00	10,368.00	10,368.00	10,368.00
Hydro power plants up	MWe	0	0	1.0	7.0	20.0	45.0
to 10 MW	GWh	0	0	3.9	27.3	78.0	175.4
Wind energy	MWe	0	0	0	0	0	45.0
	GWh	0	0	0	0	0	114.7
Solar energy	MWe	0	0	0	5.0	5.0	5.0
	GWh	0	0	0	10.5	10.5	10.5
Biomass	MWe	0	0	0	0	0	2.0
	GWh	0	0	0	0	0	12.0
Biogas	MWe	0	0	0	0	0	5.0
	GWh	0	0	0	0	0	32.5
Total production	GWh	9974.0	10,032.0	10,371.9	10,405.8	10,456.5	10,713.1
Total consumption	GWh	32,946.0	32,946.0	32,946.0	32,946.0	32,946.0	32,946.0
Participation of RES in el. energy consumption		30.3%	30.4%	31.5%	31.6%	31.7%	32.5%

and non-financial incentive measures to invest into facilities using renewable sources of energy.

Most used financial stimulating measure is the increased price of purchased energy produced by renewable sources of energy during the year. Other model deploys application of defined purchase prices for the energy produced by renewable sources of energy, so called Feed-in tariff. Most European countries apply the Feed-in tariff model.

One of the significant characteristics of the stimulating measures to increase the use of renewable sources of energy is selective stimulation of the development of chosen technologies. Besides financing research – development projects it is needed to finance installation of demonstration projects. Basic criteria for the selection of renewable sources of energy and technologies that are to be stimulated are available energy potential, ability of its own economy and degree of the international development of technologies and the market [54].

8. Conclusions

In the light of all afore said one can conclude that each day more and more CSP plants are being used for electricity generation worldwide. CSP plants are composed of solar concentrators, receiver, steam turbine and electric generator. Depending on the type of concentrator there are parabolic trough power plants, solar tower power plants, parabolic dish power plants and power plants with Fresnel reflectors. First CSP plant Solar One was installed in 1982, in USA. Nowadays there are 29 active CSP plants while 31 are being constructed worldwide. Power of parabolic trough power plants is between 0.25 and 354 MW, solar tower power plants 1.5 and 20 MW, parabolic dish power plants 1.5 MW and power plants with Fresnel reflectors 1.4 and 5 MW. The biggest active CSP plant SEGS of 354 MW is located in the Mojave Desert in USA.

Serbia has favorable climatic conditions for the construction of CSP plants. Annual average of daily energy of global solar irradiation on the horizontal plane in Serbia is less than 3.4 kW h/m^2 in the north and more than 4.2 kW h/m^2 in the south part of Serbia. Average daily global solar irradiation on the horizontal plane in July is less than 6 kW h/m^2 in the north and more than 6.5 kW h/m^2 in the south part of Serbia.

In Serbia sun irradiation is mainly utilized for the heating of sanitary water by flat collectors. Very rare are the cases of the use of solar cells to generate electrical energy. In Serbia first PV solar plant of 10 MW is being installed in Čajetina near Zlatibor. There are also plans to construct several more PV solar plants in Serbia. Law on Energy from 2004 and 2011 has brought Serbia solid legislative grounds to use more sun irradiation. In 2009 Act of the government determined the purchase price of electrical energy generated by PV plants. Public and expert audience in Serbia is hardly informed of the possibilities of electricity generation by CSP plants. Due to this fact legislative regulations do not mention utilization of renewable sources of energy by CSP plants and none of them has been yet installed. Due to favorable climatic and geographic conditions in Serbia it is possible to install CSP tower plants in Vojvodina and in other parts of Serbia parabolic trough power plants, parabolic dish power plants and power plants with Fresnel reflectors. Parabolic dishes can operate independently of power grids in remote sunny locations so they are appropriate for providing power to people living in isolated villages. More informed population on the positive experiences of the use of CSP plants in the world to generate electrical energy would contribute to a greater extent to the construction and use of CSP plants in Serbia.

Acknowledgments

This paper was done with the financial support of the project TR 33009 approved by the Ministry of Science and Technological Development of the Republic of Serbia.

References

[1] Marković D, Čeperković B, Vlajčić A, Ressl S. The white book of the electric power industry of Serbia. Belgrade: PE Electric Power Industry of Serbia; 2011.
[2] Hasan MH, Mahlia TMI, Nur H. A review on energy scenario and sustainable energy in Indonesia. Renewable and Sustainable Energy Reviews 2012;16(4):2316–28.
[3] Ummadisingu A, Soni MS. Concentrating solar power – technology, potential and policy in India. Renewable and Sustainable Energy Reviews 2011;15(9):5169–75.
[4] Parajuli R. Looking into the Danish energy system: lesson to be learned by other communities. Renewable and Sustainable Energy Reviews 2012;16(4):2191–9.
[5] Pavlović T, Čabrić B. Physics and techniques of solar energy. Belgrade: Građevinska knjiga; 2007 [in Serbian].
[6] Fernández-García A, Zarza E, Valenzuela L, Pérez M. Parabolic-trough solar collectors and their applications. Renewable and Sustainable Energy Reviews 2010;14(7):1695–721.
[7] Pitz-Paal R. High temperature solar concentrators. In: Blanco Galvez J, Malato Rodriguez S, editors. Solar energy conversion and photoenergy systems. Encyclopedia of life support systems (EOLSS). Oxford, UK: Developed under the Auspices of the UNESCO, Eolss Publishers; 2007. http://www.eolss.net.
[8] Peters M, Schmidt TS, Wiederkehr D, Schneider M. Shedding light on solar technologies – a techno-economic assessment and its policy implications. Energy Policy 2011;39(10):6422–39.
[9] Timilsina GR, Kurdgelashvili L, Narbel PA. Solar energy: markets, economics and policies. Renewable and Sustainable Energy Reviews 2012;16(1):449–65.
[10] Sharma A. A comprehensive study of solar power in India and World. Renewable and Sustainable Energy Reviews 2011;15(4):1767–76.
[11] Kaygusuz K. Prospect of concentrating solar power in Turkey: the sustainable future. Renewable and Sustainable Energy Reviews 2011;15(1):808–14.
[12] Cavallaro F. Multi-criteria decision aid to assess concentrated solar thermal technologies. Renewable Energy 2009;34(7):1678–85.
[13] Zainal Abidin Ab Kadir M, Rafeeu Y, Mariah Adam N. Prospective scenarios for the full solar energy development in Malaysia. Renewable and Sustainable Energy Reviews 2010;14(9):3023–31.

[14] Tyagi VV, Kaushik SC, Tyagi SK. Advancement in solar photovoltaic/thermal (PV/T) hybrid collector technology. Renewable and Sustainable Energy Reviews 2012;16(3):1383–98.
[15] Braun FG, Hooper E, Wand R, Zloczysti P. Holding a candle to innovation in concentrating solar power technologies: a study drawing on patent data. Energy Policy 2011;39(5):2441–56.
[16] Manzolini G, Giostri A, Saccilotto C, Silva P, Macchi E. Development of an innovative code for the design of thermodynamic solar power plants part A: code description and test case. Renewable Energy 2011;36(7):1993–2003.
[17] http://www.munichre.com/en/group/focus/climate_change/insurance_and_financial_solutions/sunny_future/graphic.aspx.
[18] Alexopoulos S, Hoffschmidt B. Solar tower power plant in Germany and future perspectives of the development of the technology in Greece and Cyprus. Renewable Energy 2010;35(7):1352–6.
[19] Medrano M, Gil A, Martorell I, Potau X, Cabeza LF. State of the art on high-temperature thermal energy storage for power generation. Part 2. Case studies. Renewable and Sustainable Energy Reviews 2010;14(1):56–72.
[20] Poullikkas A, Kourtis G, Hadjipaschalis I. Parametric analysis for the installation of solar dish technologies in Mediterranean regions. Renewable and Sustainable Energy Reviews 2010;14(9):2772–83.
[21] Beerbaum S, Weinrebe G. Solar thermal power generation in India – a techno-economic analysis. Renewable Energy 2000;21(2):153–74.
[22] http://en.wikipedia.org/wiki/Solar_thermal_energy.
[23] http://www.brighthub.com/environment/renewable-energy/articles/66917.aspx.
[24] http://www.ausra.com/technology/howitworks.html.
[25] Viebahn P, Lechon Y, Trieb F. The potential role of concentrated solar power (CSP) in Africa and Europe – a dynamic assessment of technology development, cost development and life cycle inventories until 2050. Energy Policy 2011;39(8):4420–30.
[26] http://en.wikipedia.org/wiki/List_of_solar_thermal_power_stations.
[27] Poullikkas A. Economic analysis of power generation from parabolic trough solar thermal plants for the Mediterranean region – a case study for the island of Cyprus. Renewable and Sustainable Energy Reviews 2009;13(9):2474–84.
[28] http://www.nrel.gov/csp/solarpaces/.
[29] http://www.nrel.gov/csp/troughnet/solar_field.html.
[30] Manzolini G, Bellarmino M, Macchi E, Silva P. Solar thermodynamic plants for cogenerative industrial applications in southern Europe. Renewable Energy 2011;36(1):235–43.
[31] The parabolic trough power plants Andasol 1 to 3. The largest solar power plants in the world – technology premiere in Europe, Solar Millennium AG; 2008. Available at: http://www.solarmillennium.de/upload/Download/Technologie/eng/Andasol1-3engl.pdf.
[32] http://en.wikipedia.org/wiki/The_Solar_Project.
[33] http://www.alpiq.no/en/news-stories/stories/stories.jsp?story=tcm:143-56493.
[34] http://re.jrc.ec.europa.eu/pvgis/.
[35] http://www.gizmag.com/suncatcher-solar-power-generation/12684/.
[36] http://solarcellcentral.com/csp_page.html.
[37] http://www.azcentral.com/business/articles/2010/01/22/20100122biz-stirlingsolar0123.html.
[38] http://ecogeneration.com.au/news/liddell_thermal_power_station_-_greening_coal-fired_power/002076/.
[39] http://www.novatecsolar.com/.
[40] Pavlovic M. Geographic regions of Serbia. University textbook. Belgrade: Savremena Administracija; 2000 [in Serbian].
[41] Study of the energy potential of Serbia for the use of sun radiation and wind energy. NPPE. Register no. EE704-1052A. Belgrade: Ministry of Science and Environmental protection; 2004.
[42] Pavlović T, Milosavljević D, Lambić M, Stefanović V, Mančić D, Piršl D. Solar energy in Serbia. Contemporary Materials (Renewable Energy Sources) 2011;II-2:204–20. doi:10.5767/anurs.cmat.110202.en.204P, UDK 620.92:523.9(497.11).
[43] http://solarelectricityhandbook.com/solar-irradiance.html.
[44] Tešić M, Kiss F, Zavargo Z. Renewable energy policy in the Republic of Serbia. Renewable and Sustainable Energy Reviews 2011;15(1):752–8.
[45] Golusin M, Tesić Z, Ostojić A. The analysis of the renewable energy production sector in Serbia. Renewable and Sustainable Energy Reviews 2010;14(5):1477–83.
[46] Mihajlov A. Opportunities and challenges for a sustainable energy policy in SE Europe: SE European Energy Community Treaty. Renewable and Sustainable Energy Reviews 2010;14(2):872–5.
[47] Munitlak Ivanović O, Golušin M, Dodić S, Dodić J. Perspectives of sustainable development in countries of Southeastern Europe. Renewable and Sustainable Energy Reviews 2009;13(8):2079–87.
[48] Golušin M, Munitlak Ivanović O. Kyoto Protocol implementation in Serbia as precognition of sustainable energetic and economic development. Energy Policy 2011;39(5):2800–7.
[49] Oka S, Sedmak A, Đurović-Petrović M. Energy efficiency in Serbia – research and development activity. Thermal Science 2006;10(2):5–32.
[50] Oka S, Sedmak A, Đurović-Petrović M. Energy efficiency in Serbia, national energy efficiency program-strategy and priorities for future. Thermal Science 2006;10(4):7–16.
[51] Pavlović T, Milosavljević D, Radivojević A, Pavlović M. Comparison and assessment of electricity generation capacity for different types of PV solar plants of 1 MW in Soko Banja, Serbia. Thermal Science 2011;15(3):605–18, doi:10.2298/TSCI110322065P.
[52] Djurdjević D. Perspectives and assessments of solar PV power engineering in the Republic of Serbia. Renewable and Sustainable Energy Reviews 2011;15(5):2431–46.
[53] National Assembly of the Republic of Serbia. Energy law [Zakon o energetici]. Official Gazette of the Republic of Serbia 84/04; 2004. Available online at: http://www.parlament.gov.rs/content/eng/ [in Serbian].
[54] National Assembly of the Republic of Serbia. Act for incentive measures for privileged producers of electricity [Uredba o merama podsticaja za povlašćene proizvođače električne energije]; 2008. Available at: http://www.mre.gov.rs/ [in Serbian].